Evaluation of Dwelling Unit Frame Coverage Enhancement: Case Study of the 2017 PIAAC Survey

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Abstract
This paper evaluates dwelling unit undercoverage in the 2017 U.S. Programme for the International Assessment of Adult Competencies (PIAAC), a national in-person survey of adult literacy. The survey used traditional listing of dwelling units in areas expected to have poor address-based sampling (ABS) frame coverage, and ABS elsewhere. Missed dwelling units were identified and sampled through a missed structure procedure in traditionally listed areas and through the Address Coverage Enhancement (ACE) procedure in ABS areas. Coverage enhancement procedures may reduce undercoverage bias, but they incur additional costs, and they can be time consuming. We evaluate the cost-coverage trade-offs and explore options for reducing costs of ACE without appreciably increasing the undercoverage of dwelling units.

Key Words: address-based sampling, address coverage enhancement

1. Coverage Enhancement in Address-Based Sampling

Address-based sampling (ABS) utilizes the Computerized Delivery Sequence (CDS) file of U.S. Postal Service (USPS) addresses, as provided through a vendor. While the CDS lists have high coverage overall, the coverage of dwelling units for in-person surveys is lower because non-locatable addresses, such as P.O. boxes and rural routes, are dropped from the sampling frame. Eckman and English (2012) estimated a national coverage rate of 92 percent when restricting the list to city-style addresses. The rate can vary considerably by region, state, and urban versus rural areas (Iannacchione et al., 2007; Montaquila, Hsu, Brick, English, and O'Muircheartaigh, 2009; Eckman and English, 2012; Kalton, Kali, and Sigman, 2014). For example, Dohrmann, Han, and Mohadjer (2007), estimated coverage rates under 75 percent for the rural areas in their evaluation. The CDS lists are also subject to geocoding error when assigning addresses to census geography. In Eckman and English (2012), the national coverage rate dropped to 87 percent when restricting the CDS list to addresses that geocoded with high precision (i.e., at the street level). The level of geocoding error can vary depending on the vendor and the geocoding software, and the extent of undercoverage depends on how the sample design addresses the geocoding error.

Various methods have been developed for enhancing the CDS list to improve coverage rates. Harter and English (2018) provide a comparison of three current methods: Enhanced Listing, Check for Housing Units Missed (CHUM), and Address Coverage Enhancement (ACE). All procedures are carried out within sampled segments (secondary sampling units), consisting of a census block or group of blocks. In Enhanced Listing, field staff canvass the segments to update the CDS frame prior to dwelling unit selection by adding addresses that are not on the frame and deleting those that are not found in the segment. CHUM is a two-step process after dwelling unit selection, where the first step is similar to the Half Open Interval procedure (Stephan, 1936; Hansen, Hurwitz, and Jabine, 1963), and the second involves an additional search that can help identify missed dwelling units in blocks with no addresses on the frame. As with enhanced listing, sampled addresses found to lie outside the segment are excluded.

This paper focuses on the ACE procedure. ACE is performed in a random sample of segments. Field staff canvass the segments to identify addresses that are not on the CDS list of addresses geocoded to that segment. Because of geocoding error, the addresses could be associated with another segment, so the found addresses are matched against the full CDS list to identify addresses that appear elsewhere and remove them from the list of ACE addresses. The final sample consists of all sampled CDS addresses that geocoded into the segment, plus a sample of newly identified addresses from ACE. Dohrmann, Jones, Kalton, and Opsomer (2019) provide a more complete description of the ACE procedure.

2. Coverage Enhancement in U.S. Programme for the International Assessment of Adult Competencies (PIAAC) 2017

The PIAAC 2017 was an in-person literacy survey of non-institutionalized adults ages 16 to 74, sponsored by the National Center for Education Statistics (NCES). The design consisted of a four-stage sample, with 80 primary sampling units (PSUs) made up of counties or groups of counties, 698 segments made up of census blocks or groups of blocks, 8,576 dwelling units, and 4,769 sampled persons, resulting in 3,660 completes. Section 2.1 describes the procedures implemented at the third stage of selection to develop a sampling frame for the selection of dwelling units. Section 2.2 provides some findings on the effect of the ACE procedure. The U.S. PIAAC Technical Report (Krenzke et al., forthcoming) gives further details on the sample design and weighting methods for PIAAC 2017.

2.1 Procedures

For U.S. PIAAC 2017, we opted to use a combination of traditional listing and ABS. Because traditional listing is performed within area segments, whereas ABS with ACE is based on geocoded segments, and segments need to be defined consistently within a PSU, the decision to use traditional listing versus ABS needed to be made at the PSU level. PSUs were designated for traditional listing if the ratio of the number of addresses on the CDS list to the number of dwelling units in the PSU according to the 2010 Census—the CDS-to-Census ratio—was less than 70 percent, suggesting potentially poor coverage of the CDS list. Four PSUs met this criterion. Prior to data collection, field staff canvassed the 49 sampled area segments within the four PSUs and electronically listed the dwelling units. We implemented ABS in the 649 geocoded segments within the other 76 PSUs.

We then supplemented the frame through coverage enhancement procedures. Within the traditionally-listed PSUs, a subsample of segments was selected for the missed structure procedure, which involved interviewers performing a complete canvas of the subsampled segments to identify structures that were not on the original listing. Within the ABS PSUs, we selected a probability proportionate to size (PPS) sample of approximately 10 percent of segments to receive the ACE procedure, where segments expected to have a poor CDS coverage rate had a larger measure-of-size. The measure-of-size was based primarily on the segment-level CDS-to-Census ratio and whether the segment was rural or urban. The implementation of ACE in the 67 segments followed the procedures described in Section 1.

Furthermore, an additional coverage enhancement procedure was administered in all PSUs to identify any hidden dwelling units, such as basement apartments, so they are given a chance of selection.

2.2 Findings on ACE

In U.S. PIAAC 2017, the ACE procedure improved dwelling unit coverage, but it had only a minimal effect on the survey estimates. The procedure identified 1,697 missed dwelling units, of which we randomly selected 341, resulting in 96 respondents (Table 1). While 4.3 percent of sampled dwelling units in the ABS PSUs came from ACE, only 2.8 percent of respondents did. This is primarily a result of lower eligibility rates for dwelling units added through ACE. As shown in Table 2, for ABS PSUs, 12.7 percent of the dwelling units from the original sample or hidden dwelling unit procedure were determined to be vacant, not actually a dwelling unit, or under construction, compared to 37.0 percent of dwelling units added through ACE. Despite the modest effect on yield, the ACE procedure improved the dwelling unit coverage rate by 4.2 percent.[1]

Table 1: Sample Sizes for ABS PSUs, PIAAC 2017

Stage	*Original sample + hidden dwelling units*	*ACE*
Sampled dwelling units	7,661	341
Sampled persons	4,383	134
Respondents	3,352	96

Table 2: Dwelling Unit Ineligibility Rates for ABS PSUs, PIAAC 2017

Type of ineligibility	*Original sample + hidden dwelling units (%)*	*ACE (%)*
Overall	12.7	37.0
Vacant	8.9	17.4
Not a dwelling unit	3.6	19.4
Under construction	0.2	0.2

To evaluate the effect of ACE on the estimates, we compared literacy and numeracy estimates from the full sample to estimates from the sample without ACE. Jones, Brick, and Piesse (2018) describe a similar analysis for a large-scale household survey. We computed full sample estimates using final weights, which were adjusted for nonresponse and calibrated to 2016 American Community Survey population totals for education, race/ethnicity, age, gender, country of birth, and region. For the alternative estimates, we dropped the respondents from ACE and recalibrated the final weights of the remaining respondents to the population totals. Although the average literacy and numeracy scores for ACE cases were 266.2 and 251.8, respectively (about 3 points lower than the full sample estimates of 269.1 and 255.0), given the reweighting and the low number of ACE cases, the analysis revealed no detectable difference in proficiency estimates from excluding

[1] Calculated as the number of eligible dwelling units from ACE divided by the total number of eligible dwelling units, using the design weights. The unweighted percentage is 2.9.

ACE. The reweighted estimates without ACE matched the original full sample estimates to one decimal place.

3. Improving Efficiency: Matching Evaluation

As indicated in the previous section, ACE helped improve the coverage rate of the dwelling unit sampling frame. However, we are interested in reducing the cost of the procedure for future applications. Our first step was to evaluate an alternative to the standard address matching process.

3.1 Method

As described in Section 1, in past applications addresses found by field staff through the ACE procedure needed to be matched against the full CDS sampling frame. This has been a multistep process:

1. Home office staff reviews and cleans the found addresses;
2. The addresses are sent to the vendor to match against the full CDS list;
3. Any addresses that did not match in the first round are reviewed for alternative street names (e.g., Route 355 versus Wisconsin Ave.) or other issues;
4. The addresses are sent back to the vendor for an additional round of matching.

Our evaluation compared the standard matching process to an alternative in-house matching process. Under the standard process:

- The vendor performed the matching;
- They matched the addresses to the complete CDS list; and
- The comparison was done with exact matching.

Under the alternative method:

- Westat performed the matching;
- We purchased all addresses that geocoded within a 1-mile radius (buffer zone) of the segment, and compared the found addresses from ACE against the purchased addresses; and
- The comparison used probabilistic matching.

The alternative method could potentially be more efficient by eliminating the back and forth between Westat and the vendor, and by using a probabilistic matching procedure, which could require less cleaning of the addresses. We compared the two methods in terms of accuracy (the match rate) and cost.

3.2 Results

Figure 1 shows results of the matching evaluation. Of the 2,411 addresses found by field staff as part of the ACE procedure, both matching procedures identified 600 that were elsewhere on the sampling frame. The in-house procedure matched an additional four addresses, and the vendor procedure matched an additional 110. The four identified only by the in-house procedure had a different street type on the frame than the one provided by field staff. The probabilistic matching was able to identify these as a match, and the home office staff confirmed that they were true matches. The 110 identified only by the vendor were outside of the 1-mile buffer zone.

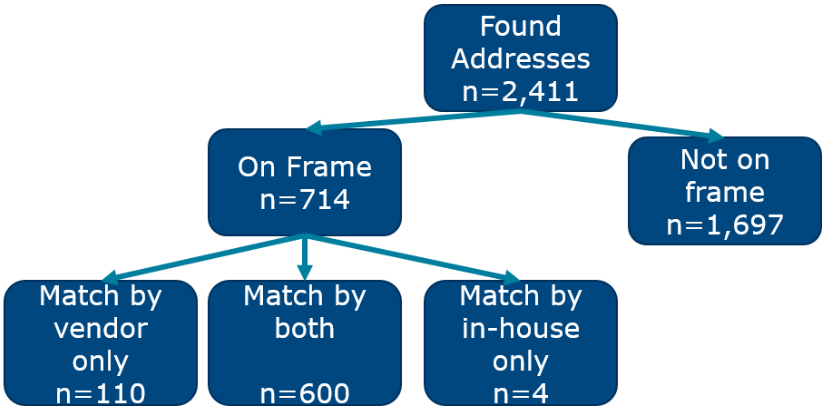

Figure 1: Results of the matching evaluation, PIAAC 2017, n = sample size after two rounds of matching

The evaluation indicates that the in-house matching method would have misidentified a large number of addresses as not being on the CDS list, and this is the result of sizable geocoding errors. Table 3 shows the border-to-border distance between the area segment and the block to which the vendor geocoded the address, for the ACE addresses from the first round of vendor matching. If we had expanded the buffer zone to 2 miles, we still would have missed over 4 percent of matched addresses, and even a buffer zone of 4 miles would not have been sufficient to capture all the addresses in the area segment.

Table 3: For ACE Addresses from the First Round of Matching, Border-to-Border Distance Between the Area Segment and the Block to Which the Vendor Geocoded the Address, PIAAC 2017

Distance	*Number of addresses*[a]	*Percent*
0 miles (adjacent)	462	71.0
0 - 0.5 miles	114	17.5
0.5 - 1 miles	16	2.5
1 - 2 miles	28	4.3
2 - 3 miles	5	0.8
3 - 4 miles	17	2.6
Over 4 miles	9	1.4

[a] Only includes the 651 addresses matched in the initial round of matching for the vendor-matching method; excludes the 59 addresses that were matched during the second round.

In addition to the lower match rate, the in-house matching method turned out to be more expensive in this investigation. However, the costs could decrease with more use and experience. Furthermore, field staff performed the same level of address cleaning for both methods, and so we have not evaluated accuracy and cost when performing the in-house matching method with more limited address cleaning.

4. Improving Efficiency: Coverage Evaluation

Our next evaluation considered the cost and coverage implications of limiting the extent of the ACE procedure.

4.1 Method

As an alternative to PIAAC 2017 design, we evaluated coverage rates under the following cost-saving options:

- *No High*: Skip ACE in segments expected to have a high CDS coverage rate, where we defined "high coverage" segments as urban segments with a CDS-to-Census ratio of one or more;
- *No Single:* Skip ACE in PSUs that had only a single segment selected for ACE; or
- *No ACE:* Skip ACE entirely.

The first option could improve efficiency by not implementing the ACE procedure in areas where it is unlikely to yield any found addresses. If ACE is performed prior to data collection, then the second option reduces costs by not having to travel field staff to a PSU to implement ACE for only a single segment. If interviewers are performing ACE during data collection, then it saves the cost of training an interviewer on ACE for only one segment.

We performed the evaluation using the PIAAC 2017 sample and estimated the loss in coverage compared to the PIAAC 2017 design as the ratio of the number of eligible dwelling units identified in PIAAC 2017 but missed under the alternative option to the number of eligible dwelling units under the PIAAC 2017 design:

$$Coverage\ loss = \frac{\sum_{j \in M} w_j}{\sum_j w_j}$$

where w_j is the base weight of eligible dwelling unit *j*, and *M* is the set of eligible DUs that would have been missed under the alternative option. We calculated the standard error of the coverage loss using the paired jackknife (JK2) replication approach.

4.2 Results

Table 4 shows the estimated coverage rates under the options described in Section 4.1. By not performing ACE in segments with an expected high coverage rate, we would have reduced the number of segments requiring ACE from 67 to 49, and lowered the coverage rate by an estimated to 1.7 percent. The results are similar when skipping ACE in PSUs with only a single segment selected for ACE. Combining the two options would result in 33 segments receiving the ACE procedure, with an estimated coverage loss of 2.8 percent. Finally, we estimate that eliminating the ACE procedure would lower the coverage rate by 4.2 percent.

Table 4: Estimated Coverage Loss Under Alternative Designs Compared to PIAAC 2017

Option	*Number of segments listed*	*Number of segments for ABS (ACE)*	*Estimated coverage loss %*	*S.E.*
PIAAC 2017	49	649 (67)	-	-
Reduce ACE				
No High	49	649 (49)	1.7	1.32
No Single	49	649 (45)	1.2	0.76
No High or Single	49	649 (33)	2.8	1.50
No ACE	49	649 (0)	4.2	1.59

4.3 Further exploration of the "no ACE" option

A possible alternative approach is to eliminate the use of ACE in a random selection of ABS segments but to increase the number of PSUs that are fully listed, either through traditional listing, enhanced listing, or by using ABS with ACE in all segments in the PSU. We used traditional listing in PIAAC 2017 in PSUs with a CDS-to-Census ratio under 70 percent. For this exercise, we tried alternative cut-points of 55 percent, 65 percent, 75 percent, 85 percent, 90 percent, and 95 percent, and we compared the predicted coverage loss under these alternatives. We assume here that the given listing method will do as well as ABS with ACE, although in practice traditional listing has generally been found to be deficient (e.g., Eckman and Kreuter, 2013).

We calculated the predicted coverage rate (*PCR*) under each alternative as the weighted mean of the segment-level coverage rates:

$$PCR = \frac{\sum_{i \in T} w_i CR_{Li} + \sum_{i \in A} w_i CR_{Ai}}{\sum_i w_i},$$

where w_i is the weight for segment *i*, equal to the inverse of the overall segment selection probability;
L is the set of segments undergoing listing;
CR_{Li} is the coverage rate for listing – for simplicity, this is assumed to be equal to 1;
A is the set of segments using ABS;
CR_{Ai} is the predicted segment-level CDS coverage rate, described below.
Here "coverage rate" refers to the coverage rate relative to ABS with ACE. The true coverage rate will be lower. The predicted coverage loss is then equal to 1 – *PCR*.

In the 67 segments that underwent the ACE procedure in PIAAC 2017, the coverage rate of the CDS list was estimated directly as the proportion of eligible dwelling units that were on the CDS list:

$$CR_{Ai} = \frac{\sum_{j \in CDS} w_{ij}}{\sum_j w_{ij}}$$

where w_{ij} is the base weight of eligible dwelling unit *j* in segment *i*, and CDS is the set of eligible dwelling units that originated from the CDS list. Twenty percent of the segments sampled for ACE had a coverage rate of 100 percent, meaning that no eligible dwelling units were added through the ACE procedure.

We then developed models to predict the CDS coverage rates for the remaining 631 segments in the PIAAC sample. Given the distribution of the coverage rates for the 67 segments, we fit a Tobit model (Tobin, 1958) on the coverage loss (1-CR_{Ai}), with weights equal to the inverse of the ACE selection probability (scaled to sum to the sample size). The predictor variables were the CDS-to-Census ratio, an urban/rural indicator, and the tract-level proportion of the population that is Hispanic or non-Hispanic Black from the American Community Survey. The resulting segment-level CDS coverage rates were scaled by a factor of 0.991 so that the overall predicted coverage rate (PCR) matched the actual coverage rate for the PIAAC 2017 scenario with four listed PSUs.

Table 5 presents the predicted overall coverage loss under different levels of listing. The first row shows the scenario with no traditional (or enhanced) listing, in which the CDS lists are used without any frame enhancement. Based on the PSUs and segments for PIAAC, the predicted loss in dwelling unit coverage rate is around 6 percent. The last row of the table corresponds to a cut-point of 95 percent. Under this scenario, 153 segments would need listing, resulting in a significant increase of cost from the PIAAC scenario. The resulting coverage loss is not an improvement over the estimated coverage losses under the options presented in Section 4.2. A reasonable cut-point may be between 70 percent and 85 percent, performing listing in four to nine PSUs. The cut-point of 70 percent corresponds to the PIAAC scenario, discussed above.

Table 5: Predicted Coverage Loss Without ACE

Cut-point (%)	*# PSUs listed*	*# Segments listed*	*# Segments for ABS*	*Predicted coverage loss (%)*
55	0	0	698	5.8
65	1	10	688	5.3
70	4	49	649	4.2
75	7	74	624	3.7
85	9	92	606	3.4
90	13	123	575	2.8
95	17	153	545	2.7

5. Summary and Conclusions

As evidenced in the prior research cited in Section 1, and confirmed by our evaluation, the CDS lists alone will not meet the coverage requirements for PIAAC. For PIAAC 2017, we effectively improved the coverage rate by performing traditional listing in four PSUs expected to be of poor coverage on the CDS list, and implementing ACE as a supplement to ABS. If the sampling frame development costs are a very small proportion of the total budget, the additional costs for ACE or traditional listing could be insignificant. However, for the next round of PIAAC, we would like to consider some cost-saving alternatives to the current method.

Using an in-house matching method to identify ACE addresses that are elsewhere on the frame did not prove effective. Given the extent and magnitude of the geocoding error on the vendor's list, it is necessary to perform the matching against the full CDS list. In addition, in-house matching did not offer any cost savings, at least in the initial attempt. A more promising option to reduce matching-related costs could be to first select a sample from all found addresses in ACE, and then perform the matching procedure on only the sampled addresses. This option is discussed in Dohrmann, Jones, Kalton, and Opsomer (2019).

Reducing the extent of the ACE process is another feasible option. Our coverage evaluation indicated that, given the 80 PSUs selected in PIAAC 2017, the following options could have reduced cost while limiting the loss in coverage:

- Forgoing ACE in PSUs with only one segment selected for ACE and/or in segments with a high expected coverage rate; or
- Forgoing the ACE procedure altogether, but performing a listing procedure in PSUs with low expected coverage rates.

Although not specifically included in our evaluation, another option is to reduce the percentage of segments selected for ACE.

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